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Status of the Fiber Optic Control System Integration (FOCSI) Program

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STATUS OF THE FIBER OPTIC CONTROL SYSTEM INTEGRATION (FOCSI) PROGRAM

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ABSTRACT

This report presents a discussion of the progress made in the NASA/NAVY Fiber Optic Control System Integration (FOCSI) program. This program will culminate in open-loop flight tests of passive optical sensors and associated electro-optics on an F-18 aircraft. Currently, the program is in the final stages of hardware fabrication and environmental testing of the passive optical sensors and electro-optics.

This program is a foundation for future Fly-by-Light (FBL) programs. The term Fly-by-Light is used to describe the utilization of passive optical sensors and fiber optic data links for monitoring and control of aircraft in which sensor and actuation signals are transmitted optically. The benefits of this technology for advanced aircraft include: improved reliability and reduced certification cost due to greater immunity to EME (electromagnetic effects), reduced harness volume and weight, elimination of short circuits and sparking in wiring due to insulation deterioration, lower maintenance costs (fewer components), greater flexibility in databus protocol and architecture, absence of ground loops and higher operating temperatures for electrically passive optical sensors.

INTRODUCTION

Fly-by-Light is used to describe the utilization of passive optical sensors and fiber optic data links for monitoring and control of aircraft in which sensor and actuation signals are transmitted optically. The benefits of this technology for advanced aircraft include: improved reliability and reduced certification cost due to greater immunity to EME (electromagnetic effects), reduced harness volume and weight, elimination of short circuits and sparking in wiring due to insulation deterioration, lower maintenance costs (fewer components), greater flexibility in databus protocol and architecture, absence of ground loops and higher operating temperatures for electrically passive optical sensors. Table I identifies the benefits of optical technology for aircraft.

TABLE I

FEATURES	**BENEFITS**
Immunity to electromagnetic effects	Improved reliability and reduced certification costs
Lower weight and volume for data links	Increased payload and/or range
No sparking or short circuits	Improved safety, no danger of explosions or fire
No ground loops	Reduction of signal noise
Wavelength and temporal multiplexing	Greater flexibility in designing protocol and architecture

If optical technology is to replace electrical/mechanical technology in control and monitoring functions of advanced aircraft, it must be demonstrated that optical technology can provide one or all of the following: solution of an existing problem; provide new functional capability; lower direct operating or acquisition costs; and/or improve safety. In addition, credible flight demonstrations must be performed and substantial in-flight operating data on components and optical subsystems must be obtained to establish reliability data on optical components and systems. Standards for connectors, fiber cables and interfaces along with specifications for testing must be established. Retraining of maintenance personnel will also be required.

The ADOCS (Advanced Digital Optical Control System) (ref. 1) program was the first large scale effort to demonstrate the use of optical sensors in active flight control systems for helicopters. Optical sensors providing information to the helicopter control increased ballistic and electromagnetic survivability along with reduced weight, volume and maintenance time. In this program optical sensors measured the position of flight control surfaces and hydraulic pressure. The optical sensors were integrated with existing mechanical and hydraulic components. Flight tests were conducted in 1987. Total flight time accumulated was over 126 hours without any major failures of the optical sensors.

A feasibility study (ref. 2-3), initiated in 1985 by NASA/DOD, concluded that fiber optic technology had the potential to improve operational reliability of advanced aircraft because of the attributes listed in table I. A program, cofunded by NASA and the NAVY, called **FOCSI** (Fiber Optic Control System Integration), evolved with a design study (ref. 4-6) of the architecture for full optical flight and propulsion control of aircraft. Following the design study, a hardware development program was initiated to build, environmentally test and fly (in piggyback fashion) a representative set of passive optical sensors for the flight and propulsion system of an advanced F-18 aircraft (fig. 1). In addition to providing credible flight demonstrations of optical sensors and optical components in an advanced aircraft environment, the FOCSI program also involved a significant number of sensor vendors with experience in this technology area. As a result of the flight tests the program will provide information on the installation, maintenance and operational problems in advanced aircraft. The remaining part of this report will deal with the FOCSI hardware development program.

FOCSI HARDWARE DEVELOPMENT

Prior to the flight tests with the full set of FOCSI hardware, some preliminary flight tests were conducted with four passive, optical sensors installed and flown on another research aircraft (F15 HIDEC testbed) at NASA Dryden. This program was valuable to the vendors who participated, enabling them to evaluate sensor performance through comparison with the production sensors. The optical sensors flown included: a compressor inlet temperature sensor, (which uses fluorescent decay); PTO (power takeoff shaft) speed (which uses Faraday magneto-optic effect); turbine discharge gas temperature (which uses the blackbody radiation principle); and, PLA (power lever angle, which uses a wavelength division multiplexed (WDM) code plate to measure position). Preliminary flight test data for these sensors are shown in figure 2. Generally the sensors performed well and compared favorably with the production sensors. These sensors have flown for a minimum of 6 hours with some of the sensors collecting up to 12 hours of flight time. Valuable information on installation problems and handling problems was obtained from these preliminary tests.

OPTICAL HARDWARE FOR PROPULSION CONTROL

The FOCSI propulsion sensors are shown in figure 3. The type of measurement along with the optical modulation technique and the vendor supplying the sensor are also shown in this figure. Typical sensors delivered for the flight tests are shown in figure 4. The sensors were all environmentally tested to the MILSPEC requirements for engine mounted hardware. Sensor range specifications are shown in table II.

A wide variety of physical phenomena are employed in these sensors for converting the measurand into an optical effect that can be measured in an aircraft environment. Engine air inlet temperature is measured by taking advantage of the temperature dependence of the fluorescence decay rate of certain crystals. The compressor inlet temperature sensor uses the Fabry Perot principle which filters or attenuates (through destructive interference) particular wavelengths, depending on the optical path length of the Fabry Perot cavity. The optical path length changes with temperature through both a change in cavity spacing and index of refraction of the material in the cavity. Fan speed is measured by using the Pockels effect. The Pockels effect is the change in index of refraction of certain birefringent crystals when subjected to an electric field. The electric field variation is caused by coupling into the eddy current sensor used to measure fan speed. Compressor speed is measured by using the Faraday effect. The Faraday effect causes rotation of the polarization of incoming light when the light passes through certain isotropic materials which have strong magneto-optic characteristics. The optical speed sensor is located in the alternator. The magnetic field variation results from the rotor of the alternator. Turbine discharge gas temperature is measured by detecting and measuring the amount of blackbody radiation, predictable from Planck's law, from a material heated by the hot gas. Actuator positions are measured by using WDM code plate or WDM (2 lambda) analog ratio. These WDM sensors operate on part or all of the spectrum of broad band light. The broad band light is dispersed unto the modulating medium (i.e., code plate or variable transmissive medium.

The sensors will be integrated with a centralized electro-optics module. The electro-optic architecture (EOA) is discussed further in the report.

OPTICAL HARDWARE FOR FLIGHT CONTROL

The FOCSI flight control sensors are shown in figure 5. Similar information, as provided for the propulsion sensors on the vendors, modulation techniques and parameters measured is provided in this figure. These sensors were also environmentally tested to MILSPEC requirements. Table II provides specifications for the sensor ranges.

Most of the sensors in the flight control measure position. The position sensors cover a number of different optical modulation techniques (WDM digital, analog, etc.). Other flight control sensors measure pressure using an analog modulation technique called microbending and an air data temperature sensor which uses the same fluorescence decay optical modulation technique as is used for measuring engine inlet temperature.

Figure 6 is a drawing of the optical fiber runs in the aircraft along with the number of connectors in each optical circuit.

Flight tests of the optical hardware will be performed on the F-18 System Research Aircraft (SRA) at NASA Dryden. These tests will be piggyback tests of the optical hardware with the data from the optical sensors compared to comparable production sensors.

TABLE II

MEASUREMENT	SPECIFICATIONS FOR RANGES
Inlet temperature	-65 to 300 degrees F
Compressor inlet temperature	-65 to 540 degrees F
Compressor speed	817 to 18553 rpm +/- .1% FS
Fan speed	3981 to 15267 rpm +/- .1% FS
Compressor variable geometry	-3.5 to 52.5 degrees
Fan variable geometry	0 to 2.7 inches
Turbine exhaust gas temperature	700 to 2500 degrees F
Exhaust nozzle position	0 to 6.923 inches
Stabilizer position	+/- 3.56 inches
Rudder position	+/- .665 inches
Trailing edge flap (TEF)	+/- 4.05 inches
Leading edge flap (LEF)	+/- 67.5 degrees
Throttle lever angle (TLA)	+/- 65 degrees
Nose wheel steering (NWS)	+/- 75 degrees
Total pressure (air data)	1.25 to 80 inches Hg
Air data temperature	-100 to 450 degrees F
Pitch stick position	+2.02 to -1.01 inches
Rudder pedal position	+/- .75 inches

ELECTRO-OPTIC ARCHITECTURE FOR PROPULSION AND FLIGHT SENSORS

One objective of this program is to develop a standard interface for the optical system. The sensor and electro-optics designers are required to meet the interface specifications for wavelength, optical power and data rates. The standard interface allows the electro-optics to handle any type of optical sensor, attached to any connector port, requiring only a change in the software to accommodate the sensors. Table III identifies the cards and card functions for the electro-optics module.

TABLE III

ELECTRO-OPTICS CARD	CARD FUNCTION
A/D optical source card	Supplies broadband light (750nm-950nm) to the sensors. Uses two LED's
A/D optical receiver	Charge-coupled device (CCD) optical to electrical converter
Data acquisition card (DAC)	Accepts electrical signals from optical receiver card and conditions data for CPU
Decode CPU	Processes the data and converts to engineering units

Time rate of decay (TRD)	Custom card for fluorescence sensor
EOA CPU	Conditions and formats data for 1553 bus
1553/1773 converter	Converts the electrical 1553 to optical 1773 data format
Power supply	Supplies power to all modules

The flight control electro-optics module and cards installed in the module are shown in figure 7 (a). A diagram of the electro-optics is shown in figure 7 (b). The optical source card contains 10 LED pairs (each pair has a 150 nm bandwidth). The LED's feed a 10 x 10 port passive coupler connected to optical fibers, which are in turn connected to the sensors. The large optical bandwidth is required by the digital code plate sensors. A smaller bandwidth source could accommodate the other sensors. The optical sources operate continuously 9 millisec (ms) on and 1 ms off. The 1 ms off period is required to clock out the data from the CCD array. The optical receiver consists of a 2-dimensional charge-coupled device (CCD) which is self-scanning. The optical signal from each sensor is focused on a specific location of the 2-dimensional array. Sensor 1 occupies row 1 followed by 3 blank rows, followed by sensor #2 with 3 blank rows, etc. The sensor signals enter the optical receiver and are focused unto the CCD array. Prior to focussing, each optical signal passes through a dispersing element that separates the 150 nm modulated signal into as many as fifteen 10 nm stripes. The CCD array output is processed and formatted by the CPU and passed to the 1553/1773 processor card which sends the signals to the data collection system onboard the aircraft. The fluorescence sensor requires a separate sensor/electro-optics card to provide a different specific wavelength range and to process the resulting optical signal. In the propulsion EOA, separate cards for the fluorescence, blackbody and speed sensors are required.

The propulsion EOA has separate electro-optics cards for the speed sensors, exhaust gas temperature sensor and inlet temperature sensor. The remaining sensors interface with the same EOA as used in the flight control.

The configuration for collection of the data on the FOCSI aircraft is shown in figure 8. Each EOA provides a 1553 output data format which is converted to the optically equivalent 1773 format and is then transmitted to the aircraft data collection system where it is converted back to the 1553 format for recording. The electro-optics used for the conversion between 1553/1773 and 1773/1553 formats is being provided to the FOCSI program by the Navy. The hardware is a product of the Navy SHARP program (Standard Hardware for Avionics Research Program). The optical signals can then be compared to the production electrical sensors which are located, in most cases adjacent to the optical sensors.

CONCLUDING REMARKS

Successful transition of Fly-by-Light technology to production aircraft will depend on flight demonstrations similar to those in the FOCSI program. Significant in-service time is required to establish a reasonable history for the technology. The true benefits of this technology and it's impact on safety and aircraft costs have yet to be evaluated. However, continued testing and continuous improvement in components must continue or this technology may never achieve it's full potential. The experience obtained from this program is valuable in promoting optical technology transfer to production aircraft, both military and commercial. This program will yield valuable information on the installation, maintenance, troubleshooting and installed testing which will be transferred to the aircraft industry. This program also involves a large number of vendors who have gained valuable experience in packaging their particular product for an aircraft environment.

Problems of standardization of optical components as well as production challenges associated with integrating optical systems into aircraft need to be addressed. To complete this phase of the Fly-by-Light program, a closed-loop flight demonstration of all-optical closed-loop operation of one or more control surfaces and the propulsion system needs to be performed. A demonstration of active control will establish the true credibility of this technology.

REFERENCES

1. Dones, F.; and Glusman, S.I.: Advanced Digital Optical Control System (ADOCS). Volume I. U.S. Army report USAAVSCOM TR 90-D-11A, Nov. 1990. (Available from DTIC as AD-B152137L.)

2. Poumakis, D.J.; and Davies, W.: Fiber-Optic Control System Integration. NASA CR-179569, 1986.

3. Poppel, G.L.; Glasheen, W.M.; and Russell, J.C.: Fiber-Optic Control System Integration. NASA CR-179568, 1987.

4. Poppel, G.L.; and Glasheen, W.M.: Electro-Optic Architecture for Servicing Sensors and Actuators in Advanced Aircraft Propulsion Systems. NASA CR-182269, 1989.

5. Seal, D.W.: Multiplexing Electro-Optic Architectures for Advanced Aircraft Integrated Flight Control Systems. NASA CR-182268, 1989.

6. Glomb, W.L.: Electro-Optic Architecture (EOA) for Sensors and Actuators in Aircraft Propulsion Systems. NASA CR-182270, 1989.

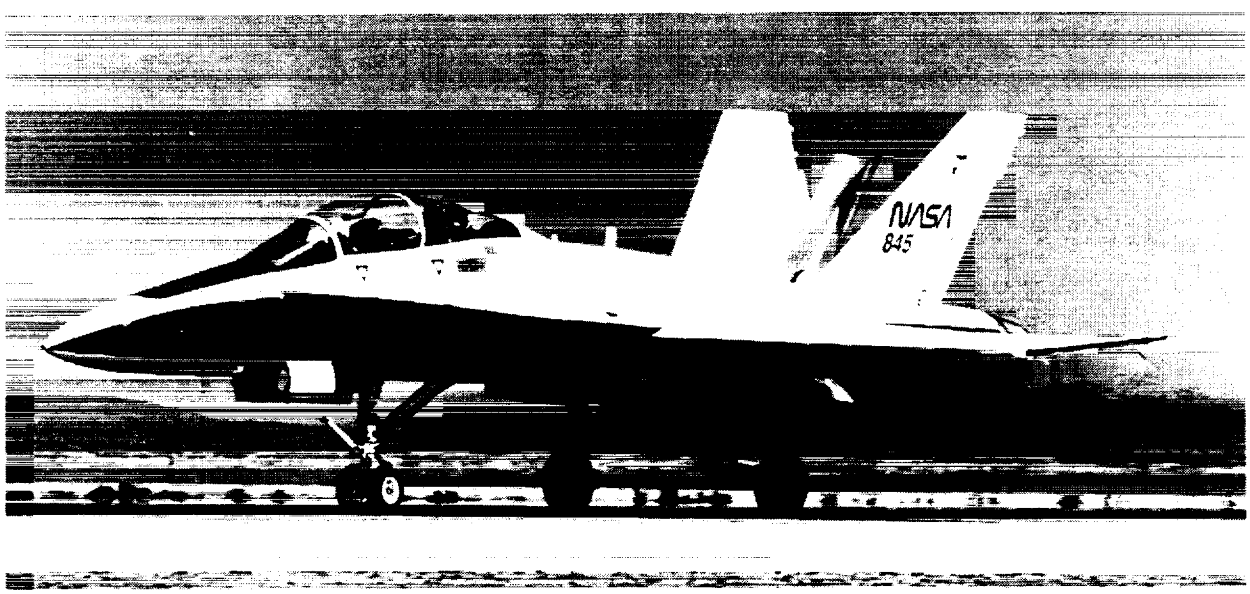
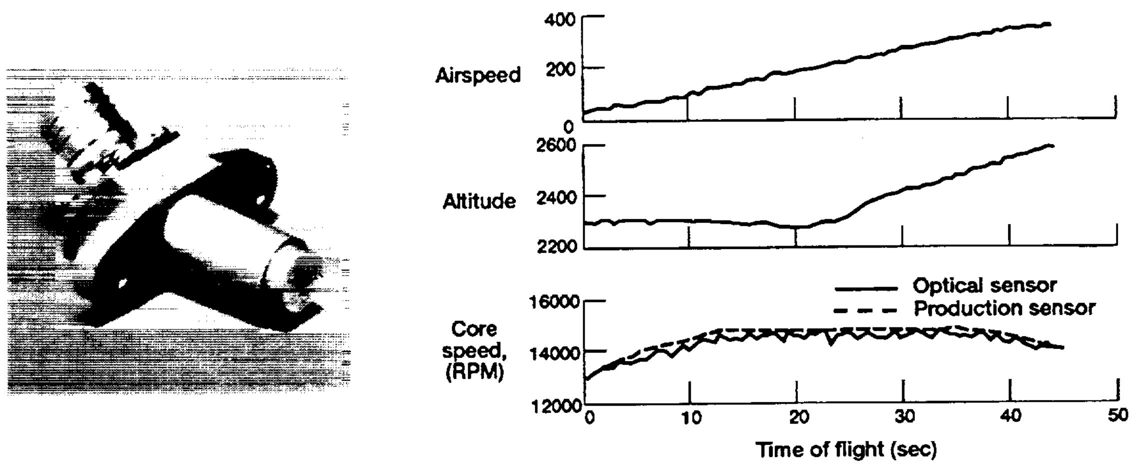
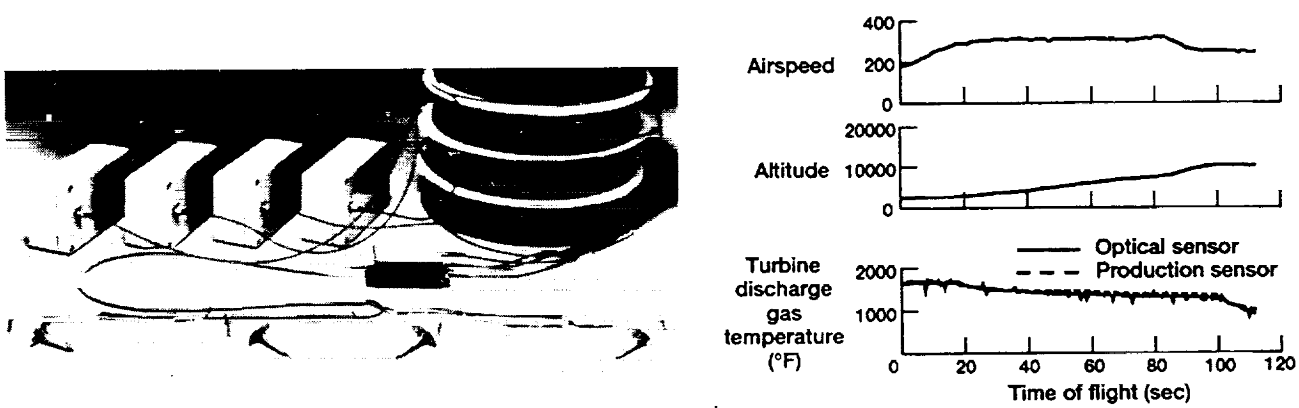


Figure 1.—FOCSI testbed aircraft (SRA/F-18).



(a) Core speed sensor; Faraday effect (Bendix Corp.).



(b) Turbine discharge gas temperature; blackbody radiation (Conax Buffalo).

Figure 2.—Flight test data of FOCSI sensors from F15 flights.

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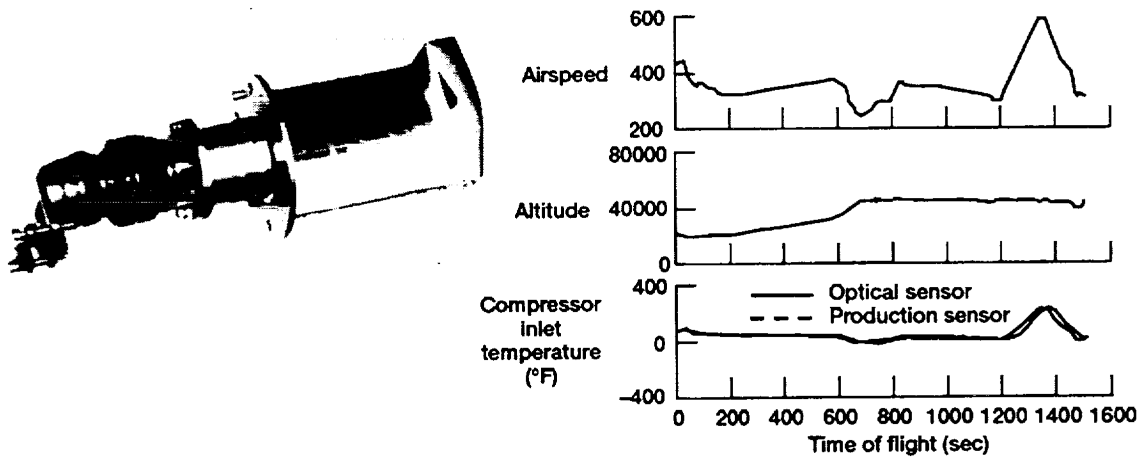
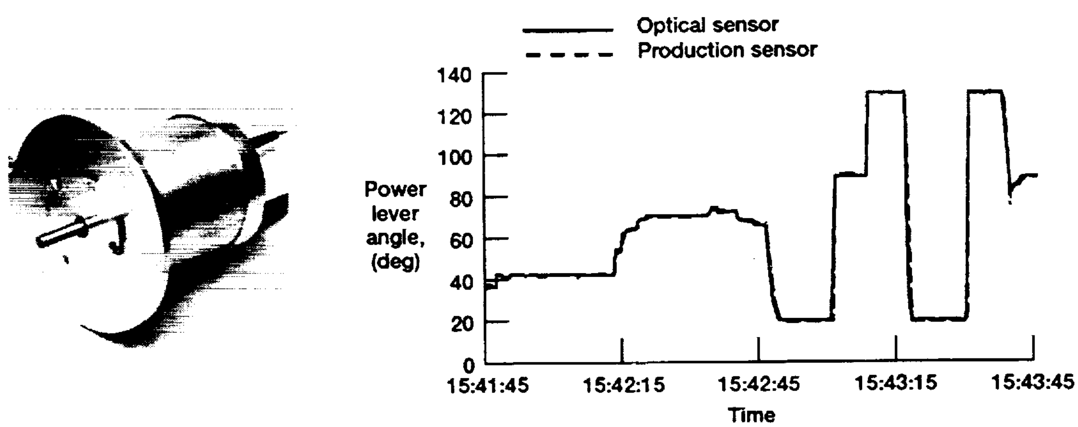


(c) Temperature sensor; time rate decay (Rosemount Corp.)



(d) NASA Lewis PLA sensor; WDM digital.

Figure 2.—Concluded.

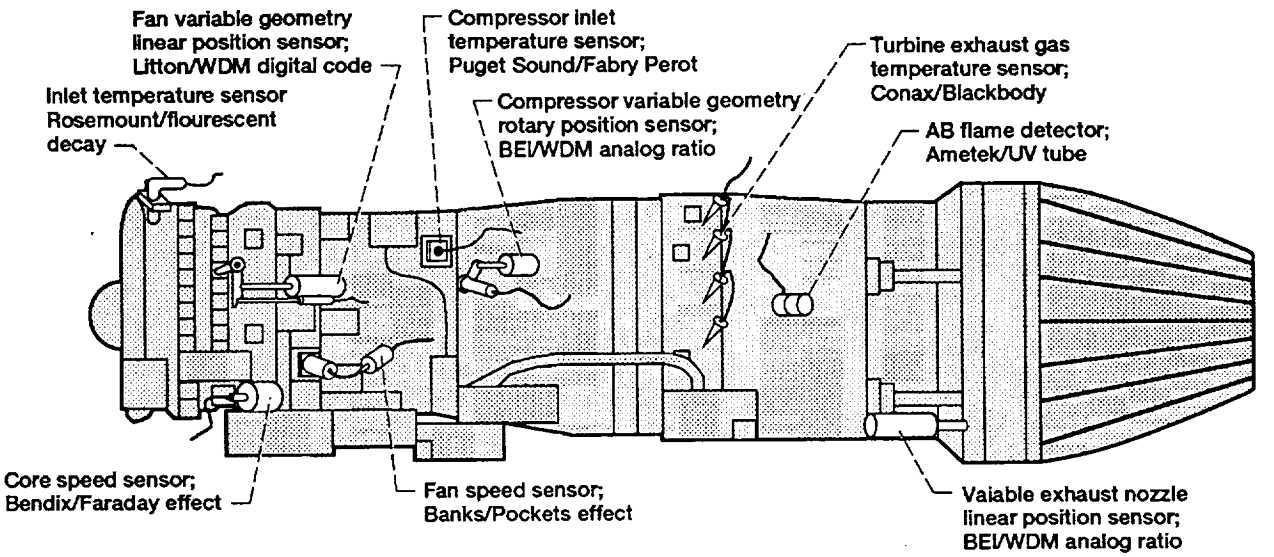
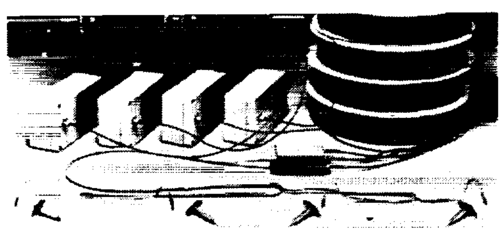


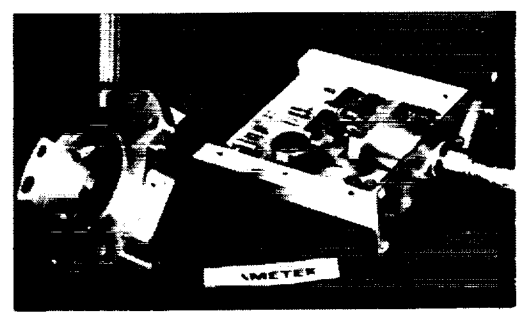
Figure 3.— FOCSI propulsion sensors.

Engine sensor
Core speed sensor
Faraday effect
(Bendix Corp.)

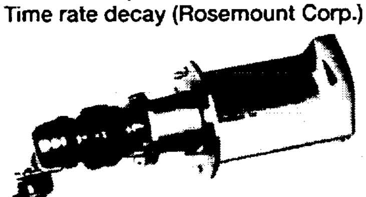
Engine sensor
Turbine discharge temperature
Blackbody radiation
(Conax Buffalo)

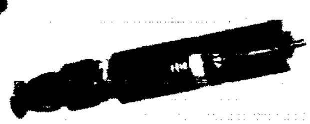


Engine sensor, Light-off detector (AMETEK)



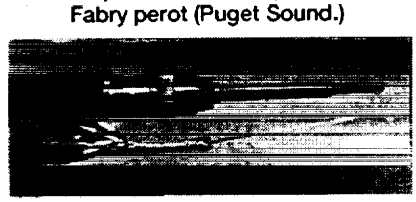
Engine/aircraft
Temperature sensor
Time rate decay (Rosemount Corp.)



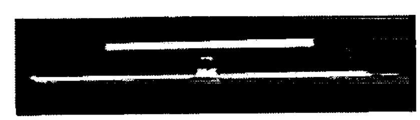


Aircraft sensor
Leading edge flap position
WDM (Allied Signal Bendix)

Engine sensor
Compressor inlet temperature
Fabry perot (Puget Sound.)



Aircraft sensor Nose wheel steering
WDM (Allied Signal Bendix)



Engine sensor, variable exhaust nozzle (BEI)

Engine sensor, compressor variable geometry (BEI)

Figure 4.—FOCSI flight qualified optical sensors.

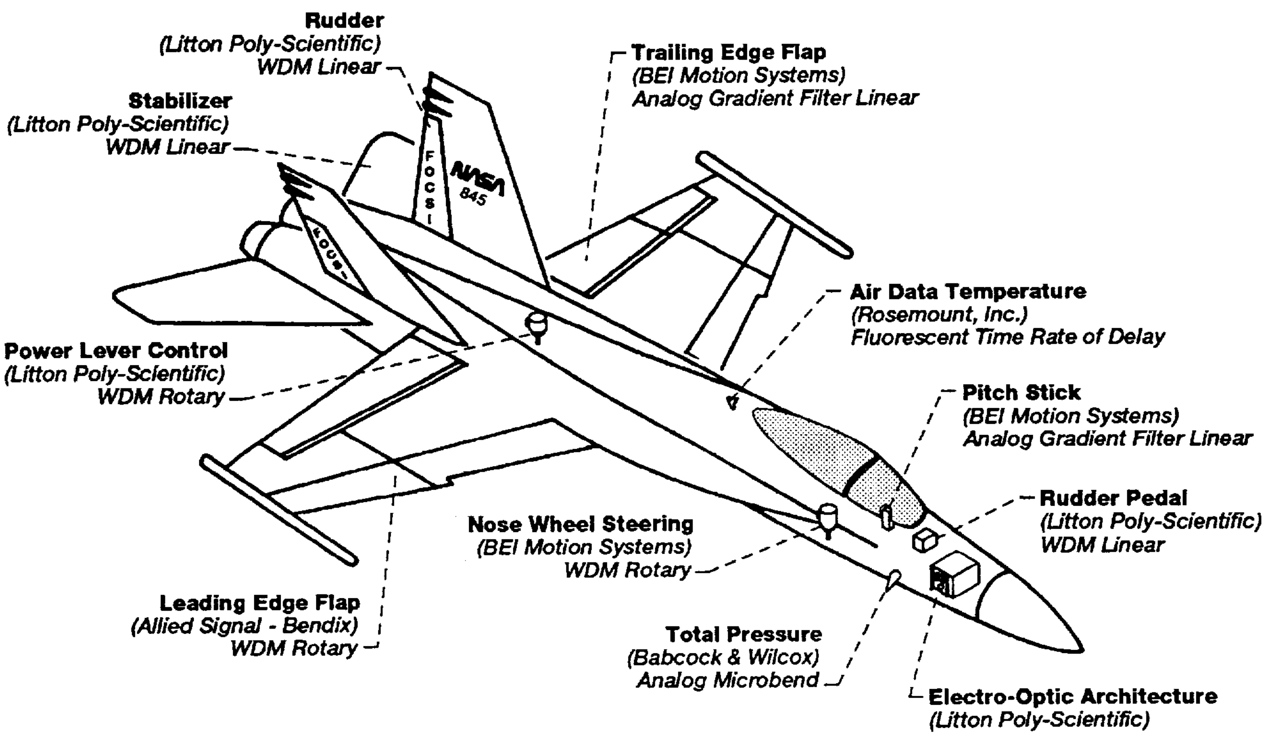


Figure 5.— FOCSI flight control sensors.

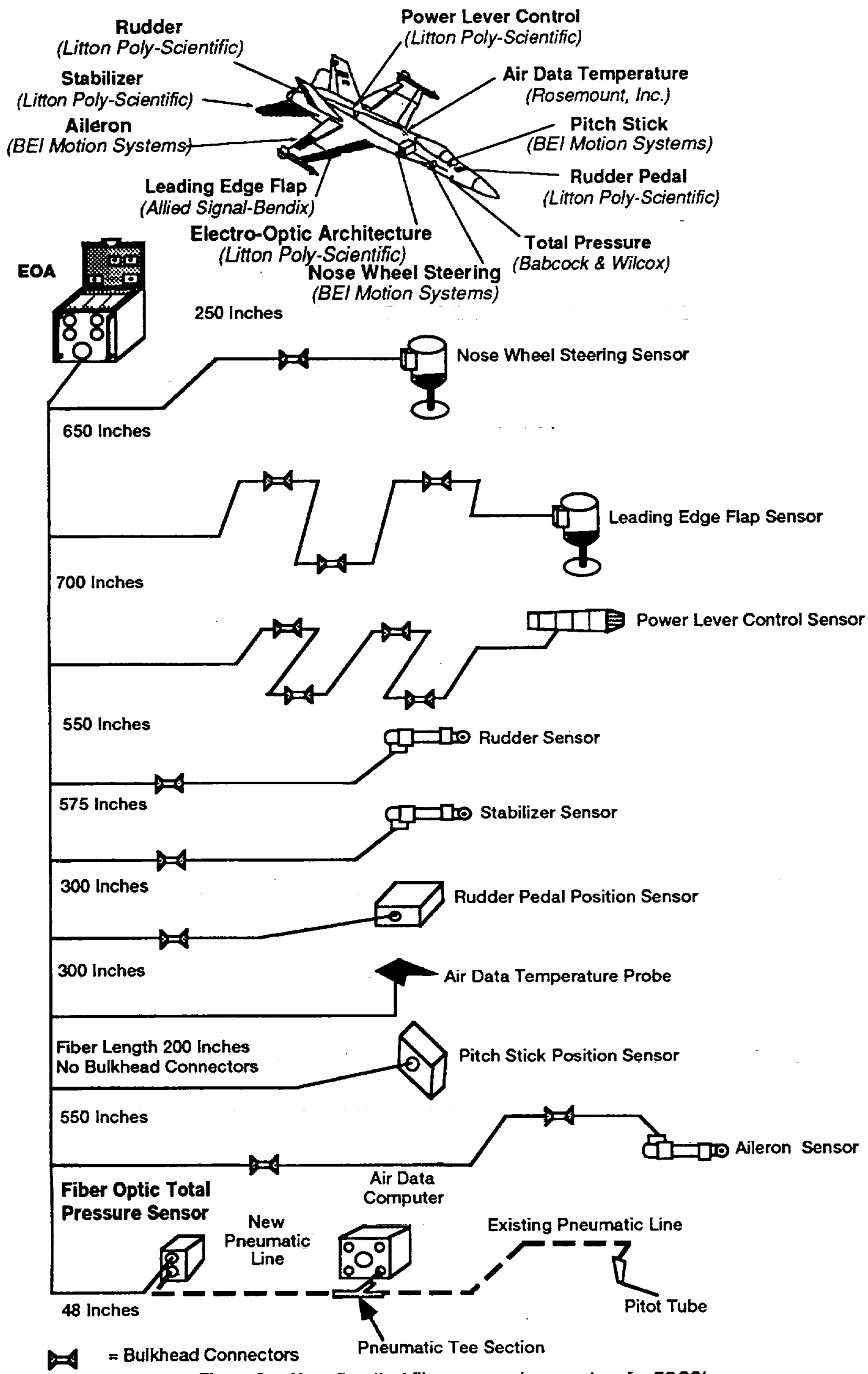
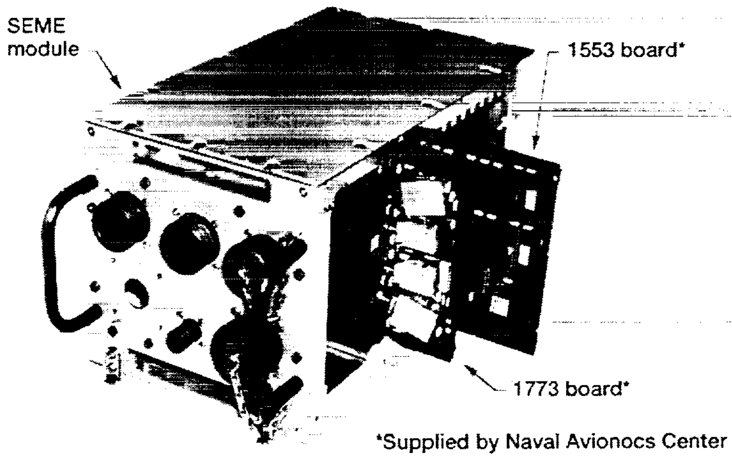
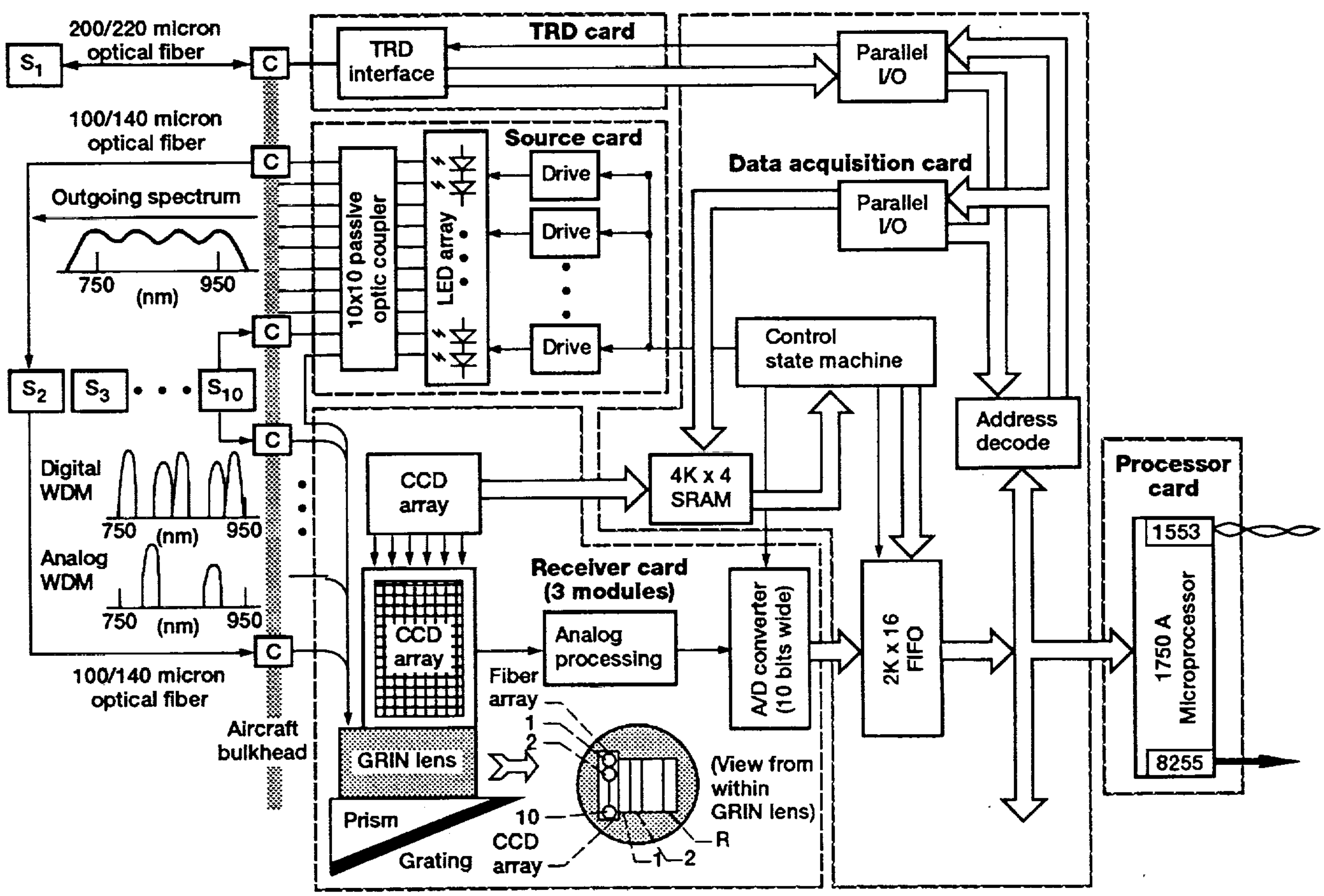


Figure 6.—Aircraft optical fiber runs and connectors for FOCSI.



(a) FOCSI EOA built by LITTON, Aircraft EOA SEME module.



(b) WDM EOA functional block diagram.

Figure 7.—Electro-optics unit for flight control.

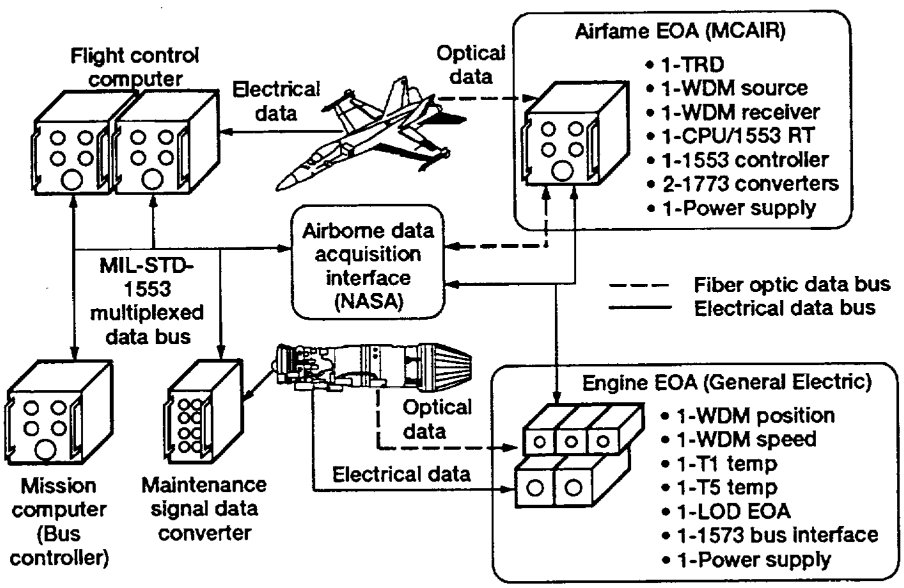


Figure 8.—FOCSI architecture for on board flight test data collection.

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